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Linking American Businesses to Missile Defense Technology
www.mdatechnology.net

INSIDE

The Age of Advanced Materials —*by Adam Gruen*

21st century materials are lightweight, strong, flexible, and versatile. New companies hope to make them ubiquitous.

The materials we use in construction and transportation and to create weapons and tools are so fundamental to our existence that historians name ages after them: stone, bronze, iron, and steel. With the advent of ceramic and carbon fiber composites and graphite nanofibers applied as thin films and coatings upon (and within) hundreds of different kinds of substrates, our ability to build artifacts that can conduct electricity and withstand heat and corrosion has improved dramatically. Scholars may one day look back upon this time and call it the Age of Advanced Materials.

Advanced materials are initially expensive to produce and apply, and as a result markets are slow to evolve. The role of government agencies—the Missile Defense Agency (MDA) prominent among them—is twofold: to set goals for desirable physical properties (in lieu of customer requirements); and to encourage companies to reduce production costs. In each of the following cases, MDA helped fund young companies during their critical "pre-commercialization" stage of growth.

Cerablak™

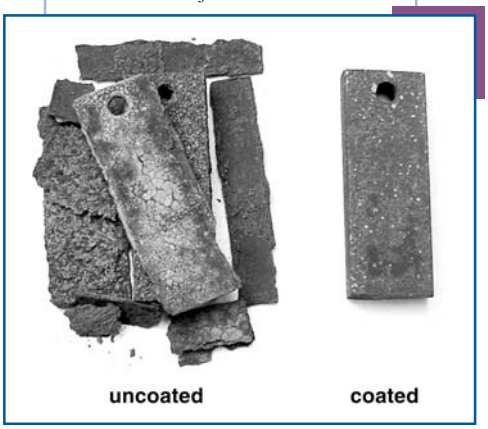
Some of the most famous discoveries in the history of materials have been accidents, including Kevlar® and Teflon®. Add to that list: Cerablak™.

A new high-temperature amorphous oxide material was discovered in late 1997 when chemists experimented with different solutions for ceramic composite matrices. Applied Thin Films, Inc. (Evanston, IL), is exploiting this discovery for a broad range of applications. Combining aluminum, phosphorous, and oxygen, it created an oxide that could easily be applied as a micron-thin coating upon a substrate. The ultra-thin film withstood temperatures up to 1200ºC without crystallizing or degrading, and it provided a smooth, hermetic seal.

The Ballistic Missile Defense Organization (BMDO), the precursor to MDA, wanted to learn more about this surprising new technology that offered a relatively inexpensive way to obtain a lightweight, heat- and corrosion-resistant coating. In 2001, BMDO funded the company with an SBIR Phase I contract to prove that the coating could survive thermal stresses at the interface of the film and its substrate, and to test Cerablak's tribological properties. The weakness of most other ceramic coatings is that they do not provide adequate protection at elevated temperatures and they crack during thermal cycling.

Applied Thin Films named its discovery Cerablak because researchers learned that carbon impurities left behind in the organic precursor solution, when baked at 1100ºC, turned the material jet black. This suggested not only a name for the material, but also an important property: low diffusivity. The carbon did not get out; oxygen did not get in. The coating could be used to prevent oxidation in high-temperature conditions. Subsequent investigation revealed

Continued on page 14



Heat wave. *Pictured above is uncoated and Cerablak™-coated stainless steel after 100 hours at 1,000ºC in ambient air.*

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Coming soon:

A Joint Technology Development with Industry solicitation. Look for the BAA at www.mdatechnology.net in mid October. For more info, call Mr. Paul Koskey at (703) 697-3639 or Ms. Leslie Aitcheson at (703) 697-3691.

FROM THE EDITOR

ONE OF THE BEST MARKETING TOOLS AROUND

The newsletter you are holding right now is one of the best marketing tools around. So say many MDA-funded technologists.

When you're tinkering around in the lab, there's not a lot of time to think about technology marketing. But it is essential to succeed in commercialization. Marketing is all about spreading the word about your technology. It can help create product sales, generate publicity, and attract financing and potential partners.

The *MDA Update* helps MDA-funded technologists get the word out. The printed version of the newsletter is circulated to over 7,000 people—chief executive officers, R&D directors, venture capitalists, government program managers, etc.—that are very interested in reading about new technology developments. Dialogues take place between the technology developers and those interested in the technology and business relationships develop as a result.

Clinton updated. *In a presentation to Hillary Clinton, AMBP Technology Corporation described its MDA-funded assisted molecular beam process. The former First Lady also received a reprint of AMBP Tech's* MDA Update *article.*

The Web version of the newsletter has been particularly effective. For example, the *MDA Update* is still generating contacts for Aguila Technologies, long after the company appeared in the Spring 2001 issue. "I have averaged about one inquiry per week resulting from people using search engines to find our *MDA Update* article on your Web site," said Al Capote, the company's president. "It has been a tremendously successful market outreach tool for us. Thank you so much for this visibility."

After being published, MDA-funded technologists receive reprints of their *MDA Update* articles. The reprints put a singular focus on each technology and add credibility to it by having MDA's technology transfer information and the newsletter's masthead included. And they can be printed easily on a color printer or at a local copy center like Staples, Kinko's, or PIP Printing.

Reprints are great to hand out in business situations like meetings and presentations. They also work well in media kits. "The reprint of our Summer 2002 *MDA Update* article looks great," says Jim Garvey, president of AMBP Technology Corporation. "Senator Hillary Clinton will be visiting our company soon and I plan on giving her an information package that includes the reprint. She will be most impressed."

When the *MDA Update* makes marketing this easy, who wouldn't say the newsletter is one of the best?

Patrick Hartary
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UP FRONT

MAKER OF STRONG POLYMERS OPENS PLANT IN SOUTHEAST

A California company that invented what it hails as "the world's strongest and hardest polymers" has set up a new company and a new plant in Mississippi.

Maxdem, Inc. (Winter 1995 issue; "Plastic With the Strength of Steel"), created its family of scratch-resistant thermoplastic polymers with help from BMDO SBIR funding to develop rigid-rod polymers. The tough polymers have been envisioned in a host of missile-defense applications: in composites for missile components, on printed circuit-board substrates, and even in scratch-proof windows or displays.

The new company, Mississippi Polymer Technologies, Inc. (MPT), began operating in January 2000 and this spring opened a 20,000-square-foot research and processing pilot plant in the Port Bienville Industrial Park in Pearlington, Mississippi.

Robert R. Gagné, president of MPT, said the new company is focused specifically on the family of Parmax® Self-Reinforced Polymers (SRPs) developed by Maxdem. The structure of the polymers gives Parmax SRPs a rigid-rod "backbone" that imparts exceptional strength and stiffness while also giving the polymers their processibility.

For structural applications, manufacturers often reinforce conventional plastics with fibers, but Parmax SRP plastics have enough strength without added fibers, according to the company. MPT officials say that the self-reinforced polymers are two to four times stiffer than any other thermoplastic. Moreover, they say the company's polymers are two to three times stronger than any other thermoplastic.

That strength and stiffness means these polymers could replace steel or metal in applications such as ammunition cases, lightening the load for aircraft that transport military supplies. The polymers have application for wing components also, according to Gagné. He said that, pound for pound, Parmax SRPs could rival aluminum or titanium alloys in aerospace applications. "I think it's one of the most important invention in structural polymers since the invention of nylon 60 years ago," Gagné said. "It's inevitable that you're going to find applications."

MPT will seek to make applications practical by refining production techniques. In California, Maxdem initially produced polymers in batches of only a few pounds at a time. But the new MPT plant can produce batches of about 100 pounds each, according to Gagné.

Tax incentives and building assistance from state and local government influenced the choice of Mississippi for its new company. Gagné said the proximity of the University of Southern Mississippi was also a draw because it has a strong academic program in polymer science.

Funding from U.S. Army and U.S. Air Force SBIR contracts, as well as private licensing agreements, will provide the initial money MPT needs to operate its new pilot plant.

—L. Scott Tillett

Uses for Strong Polymers

Blends and Additives

Parmax SRPs can be added to other polymers to improve solvent resistance, flame resistance, creep, and mechanical properties.

Films and Coatings

Using organic solvents and Parmax SRP derivatives, MPT can prepare transparent films that then can be heat-laminated onto polycarbonate sheets to form clear protective coatings. Possible applications include abrasion-resistant laminates and flexible electronic substrates. Organic solvents can also be used to create transparent, pale-yellow Parmax SRP solutions used in clear coatings on substrates (e.g., scratch-resistant liquid crystal displays).

Molded Parts

Parmax SRPs can be compression-molded, extruded, and injection-molded to produce transparent to semitransparent yellow parts. The extremely hard finished parts have high solvent resistance and are un-affected by water. Parmax SRP parts also can be machined and finished using standard equipment. The Parmax SRPs behave, in general, like aluminum, according to company officials.

New digs. *MPT opened this 20,000 ft² pilot plant in the spring. Officials expect the plant to employ 30 people next year.*

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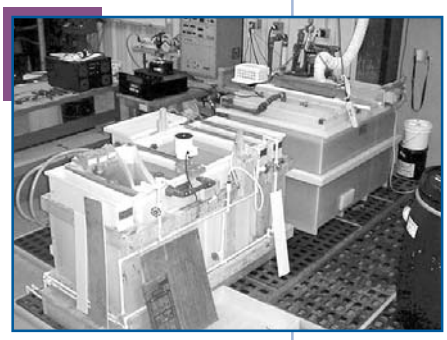
ADVANCED MATERIALS

MODIFIED WAVEFORMS TO SIMPLIFY ELECTROPLATING



No additives. *Faradaic™ Leveling uses electrical rather than chemical means to deposit and remove metals. Because the process is additive-free, it is less costly and more environmentally friendly than conventional electroplating.*

Faraday Technology has developed an extensive library of sophisticated waveforms tuned to specific metals, features, size ranges, and aspect ratios.

One goal of semiconductor and printed circuit board manufacturers is to create devices having submicron features. But making such devices has been held back because depositing metallic films inside high-aspect-ratio features—trenches, vias, and through holes—is very difficult.

Today, high-aspect-ratio features are electroplated and filled using simple variations in current at different stages in the electroplating process and by using chemical additives, called levelers, to suppress plating at various locations on the substrate. Levelers require strict monitoring and control of the chemistry of the electroplating solution, subsequently increasing production costs. Because of their toxicity to the environment, using these chemicals incurs additional costs for proper handling and disposal.

To enable precise control of electroplating using electrical rather than chemical means, Faraday Technology, Inc. (Clayton, OH), has developed their Faradaic™ Leveling process that uses modified current or voltage waveforms to selectively deposit metals in certain submicron features. In the process, a substrate having an electrically conductive "seed layer" and a counter electrode are immersed in an electroplating bath containing ions of the metal to be deposited. A short cathodic pulse causes a thin layer of metal to be deposited onto one area of the substrate. This may be followed by a short anodic pulse to remove unwanted, excess material from another area. This waveform-modulated, polarity-reversing current is specifically selected to provide proper coverage and fill. Faraday continues to add to their extensive library of sophisticated waveforms tuned to specific metals, features, size ranges, and aspect ratios. This library, along with Faraday's expertise, allows them to select the appropriate waveforms for additive-free, uniform electrodeposition of metals in very small features.

Simplicity is at the heart of the technology. "Conventional electroplating relies on complicated chemical formulas to deposit and remove metals," said Philip Miller, Faraday's business development manager. "The situation gets even more confusing when many different metals must be deposited. With our additives-free Faradaic Leveling process, deposition is controlled simply by asymmetric waveforms." High-density interconnects, which are key to making advanced electronic modules used in missile defense systems, can now be made faster and more affordably. BMDO funded this work through SBIR Phase I and II contracts.

Faraday's process has additional uses. It can be used to deposit uniform layers of metals on the surfaces of large semiconductor wafers and objects with intricate geometries. The process can also be used to selectively etch material by modulating voltage rather than current. Faraday has used the process for special etching applications, including electropolishing of the internal surfaces of stainless steel semiconductor fluid delivery valves. Even very passive metals, such as nickel, titanium, aluminum, chromium, and their alloys, can be etched using the Faradaic process.

Several alliances have been formed to develop an integrated electrochemical deposition system based on the Faradaic Leveling technology. Faraday has teamed with Ludy, an electroplating equipment supplier that is providing specialized processing tanks. Faraday has also allied with Dynatronics, which supplies the electronics to control the waveforms.

In a strategic technology alliance, Faraday and Multilayer Technology, Inc. (Multek), a wholly owned subsidiary of Flextronics International, Ltd., have agreed to jointly develop and refine this technology. As part of this arrangement, Multek has provided approximately $700k in development funding and is allowing Faraday personnel access to one of its advanced plating facilities to conduct experiments. Faraday is scaling up the process using test panels supplied by Multek.

—P. Hartary

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FLAMING THE MIST: CCVD NANOPOWDER PRODUCTION

Igniting an aerosol spray is something you should never try to do—unless you intend to produce and collect nanopowders.

It's called combustion chemical vapor deposition (CCVD), a technique originally invented to deposit thin films on substrates. Micro-Coating Technologies, Inc. (MCT, Atlanta, GA), uses the same basic technology to create a variety of metal and ceramic nanopowders for applications including catalysts, chemical-mechanical polishing, and pigments.

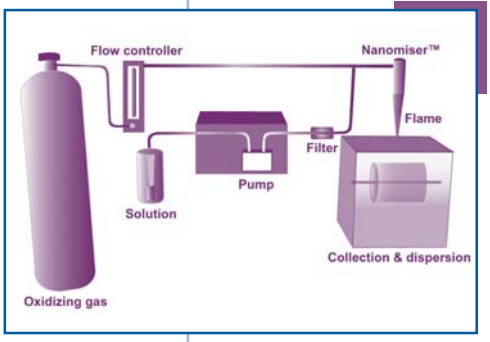
In 1999, BMDO funded MCT with an SBIR Phase I contract to prove that CCVD could be used successfully to make nanopowders with desired size and morphology. Subsequently, BMDO awarded a Phase II follow-on contract to MCT to optimize the process, to develop an efficient collection system, and to scale up an affordable method of production. Early collection efforts yielded up to 20 percent nanopowders with desired properties and MCT claims its yield now approaches 80 percent in research quantities. It hopes to have a process in place within six months to produce kilograms per hour.

The key to MCT's success is a patented nebulizer called the Nanomiser® device. A precursor solution consisting of materials dissolved in organic solvents is pumped to the Nanomiser device which atomizes the solution into submicron-size droplets. The droplets are carried by convection to a flame where they are vaporized and combusted. The resulting vapor cools and forms particles. By adjusting process parameters, chemists can vary the quality and quantity of nanopowders produced. For example, cerium oxide nanopowder intended for chemical polishing and electrolyte applications can be made in particle size ranges between 6 and 30 nm.

This approach has potential advantages including ease of synthesis of complex oxides, high purity, good particle size control, high yield and low-cost production. MCT capitalizes on these benefits by targeting applications such as catalysts, chemical mechanical polishing, and solid oxide fuel cells.

MCT intends to pursue one of three strategies as the nanopowder market matures. The first would be to license its technology for a specific field of use and sell the Nanomiser device to the customer. The second is to manufacture and sell nanopowders. The third would be to find a potential partner for a joint-venture arrangement. The company invites inquiries from interested parties who would like to know more about the Nanomiser device and its products, or about possibilities for licensing or partnership.

—A. Gruen



When the mist burns off. *The Nanomiser™ device is the key to high-yield, low-cost nanopowder production.*

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A Glimpse of MDA Technology Investments, Dividends

The Missile Defense Agency has envisioned a missile defense system to detect, intercept, and destroy missiles before they hit their targets. This system requires substantial investments in state-of-the-art technology, such as computers, communications, materials, and sensors. The vast majority of these technologies will take years to mature before they can be inserted directly into a deployable system. In the meantime, some will find success in the commercial market—an environment that often helps refine technologies too risky or unproven for missile defense.

For *MDA Update* readers interested in MDA technology investments and their dividends, the MDA Technology Applications program has developed a new report. The Missile Defense Agency's *2001 Technology Applications Report* features 26 advanced technologies that have met with commercial success, are being used in MDA systems, or both. To receive a free hard copy of the report, call (703) 518-8800, ext. 500, and leave your name and mailing address. The new report can also be found online at http://www.mdatechnology.net/reports.asp.

AMBERWAVE MERGES SILICON, COMPOUND MATERIALS

AmberWave Systems' SiGe interlayer solution could redefine the silicon roadmap by combining the speed of GaN and InP materials with the cost and manufacturing infrastructure of silicon.

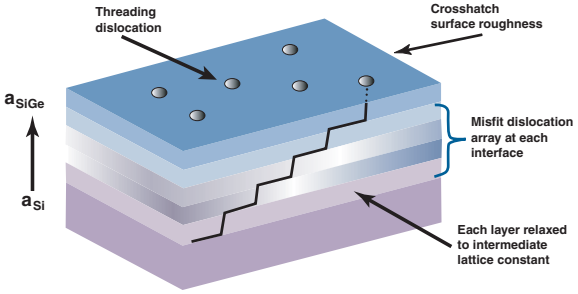
It's been the dream of the semiconductor industry for years—combining silicon (Si) with high-speed, opto-electronic semiconducting materials like germanium (Ge) and gallium arsenide (GaAs), all on a single wafer.

Making this vision a reality, AmberWave Systems Corporation (Salem, NH) has devised a way to combine these two different types of materials. The new technique will significantly reduce the cost of opto-electronic devices ranging from space solar cells to communications lasers. More exciting is that the technology may soon enable new integrated devices such as high-performance opto-electronics with Si microelectronics on a single chip.

Typically, silicon and compound semiconductor materials can't be combined because of their different crystal structures. This disparity creates stress between the materials and ultimately causes devices to fail. AmberWave gets around that by building a buffer layer on the Si substrate. Layers are deposited from 100-percent Si to 100-percent Ge with a SiGe interlayer. Patented chemical-mechanical polishing techniques are used to eliminate surface crosshatch roughness and minimize any line defects that could create preformance problems for devices created on top of the SiGe interlayer.

The potential of AmberWave's SiGe interlayer technology has been successfully demonstrated by creating detector-type devices, including single- and dual-junction AlGaAs/GaAs and InGaP/GaAs photovoltaic cells. The goal for these devices is comparable performance to solar cells made with III-V compounds on Ge substrates but with lighter weight, lower cost, and improved robustness. The company estimates the weight decrease for replacing a Ge substrate with silicon to be 65 percent, which would more than double the power output per unit of weight. In addition, Si substrates can be produced in larger diameters than Ge substrates, which leads to a 50-percent cost reduction in manufacturing.

A more difficult task is creating emitter-type devices, such as communications lasers, that integrate the functions of compound materials and silicon on a single chip. AmberWave is currently building a 980-nanometer laser that will eventually be integrated with Si microelectronics for on-chip and chip-to-chip input/output functions. A prototype developed at MIT based on technology licensed by AmberWave already shows life spans of several hours.



Virtual substrate. *Researchers at AmberWave Systems can grow layers of silicon germanium on top of a silicon wafer while minimizing threading dislocations.*

AmberWave is developing the solar cells and laser with the help of SBIR Phase I and II funding from BMDO, which is interested in reducing the cost and improving the performance of these technologies for missile defense applications. In addition, the company has raised over $45 million in additional funding through venture capital firms such as Adams Capital, Arch Venture Partners, TeleSoft Partners, and The Hillman Company.

Currently, AmberWave is looking for development and commercialization partners from the solar cell and high-speed communications industries.

—P. Hartary

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GaAs FEEDS THE NEED FOR INSTANT GRATIFICATION

Within two years the number of people surfing the Internet is expected to nearly double—from 533 to 945 million people—creating an electronic traffic jam of slow downloads in the cyber world, according to the Computer Industry Almanac. What will that do for Internet speed? Download times, although only seconds long, are not holding our ever-decreasing attention spans. However, fiber-optic cable is opening up a new world of quick downloads and real-time access to the information you want. Now, new materials for fabricating optoelectronic devices will allow fiber-optic network service providers to process more information faster and cheaper.

Gallium arsenide (GaAs) is the material of choice for next-generation telecommunications. Essential Research, Inc. (ERI; Cleveland, OH), a materials company with expertise in GaAs and other compound semiconductor materials, is meeting market demand by developing GaAs wafers, dies, and devices. ERI was funded by BMDO to develop a solar-driven thermophotovoltaic electrical system for space power applications that will not degrade from radiation exposure. ERI used the knowledge gained in this research to develop optoelectronic devices using GaAs, indium gallium arsenide (InGaAs), and indium phosphide (InP).

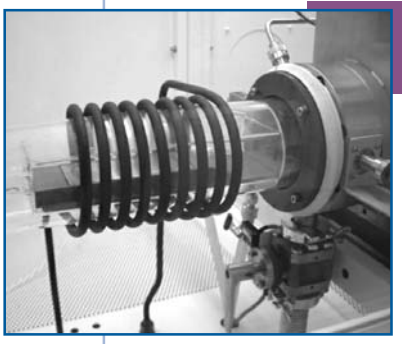
Optoelectronics comes from the combination of electronic and photonic means to send information. Although silicon is the dominant material used in electronics devices, InP and GaAs have better optical qualities. GaAs has ten times more power amplification abilities than silicon, allows for smaller packages, better performance with less distortion in the signal, and superior optical properties.

ERI has established a customer base in the United States and Europe. The company is currently selling two-inch InGaAs, InP, and GaAs wafers and dies in the telecommunications market and will be manufacturing three-inch wafers within the year. It is now expanding its capabilities into manufacturing optoelectronic devices by developing InGaAs PIN diodes and GaAs optical detectors. The company's first product, InGaAs PIN diodes grown on InP substrates, are being developed to commercial specifications.

Although ERI is currently interested in focusing only on its GaAs wafers and devices, another telecommunications application being developed is the monolithic integrated module (MIM). MIM is a fabrication of many individual components on a single chip to produce high speed at low power.

Last year, ERI earned $250,000 in wafer and die sales. The company expects to enter the GaAs device market within a year.

—T. Spitzer



Need for speed. *ERI's deposition tool is key to making compound semiconductor wafers and devices that allow fiber-optic networks to process data faster.*

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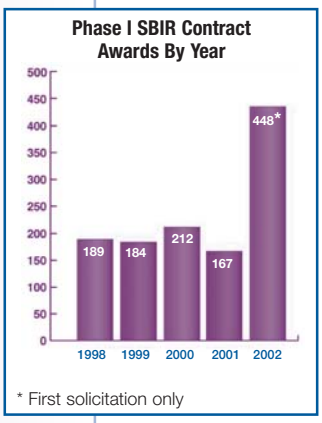
MDA Selects More Phase I SBIR Winners

With a larger budget and a greater number of proposals addressing mission-relevant technologies, MDA has already selected more than twice as many Phase I SBIR winners as in 2001—and additional selections are expected before year's end. "When missile defense became more of a national priority, MDA's overall budget increased from $4 billion (FY 2001) to $7 billion (FY 2002)," said Frank Rucky, MDA's SBIR program manager. "Accordingly, MDA's SBIR program budget grew from $80 million (FY 2001) to $136 million (FY 2002). With more money and more proposals, we can make more selections."

January's Phase I SBIR solicitation attracted 1,026 proposals; 448 were selected. The latter figure includes 66 technologies recently transferred from the U.S. Air Force to MDA due to the Department of Defense's restructuring of missile defense responsibilities. A second solicitation is planned in August, with awards being made by January 2003. Mr. Rucky expects MDA will fund an additional 100 to 150 projects from this solicitation.



ADVANCED MATERIALS

SOUTHBOUND SET MARKS A TRAIL OF UNIVERSITY RESEARCH

PALE to scale. *SET uses its PALE process to reduce gate leakage in its high-power transistors by four to six orders of magnitude. Pictured above is PALE processing equipment used by the company.*

Regardless of application, the devices made from wide bandgap materials are seen to be more stable, have longer lifetimes, and operate at higher powers than their silicon and gallium arsenide counterparts.

Sensor Electronic Technology, Inc. (SET; Latham, NY), is developing and commercializing advanced electronic devices based on wide bandgap semiconductors as a result of funding over the past several years through MDA's advanced technology and SBIR programs.

Aside from increasing power levels and reducing the size of MDA's radar systems, wide bandgap materials can serve as an improvement for a host of commercial applications ranging from wireless communications to medical detection. They can also be used to make white light-emitting diodes—an important enabler that could revolutionize the entire lighting industry by replacing existing incandescent and fluorescent lighting with a brighter and far more energy efficient alternative. One study suggested that white LEDs, if fully implemented, would save up to $115 billion per year in electricity by year 2015, thus reducing air pollution and other waste generated from power plants.

With much potential and so many benefits, several companies and research institutes have worked in this area since the mid-1980s (depending on where and when you start counting), especially in the area of silicon carbide and more recently, gallium nitride. The material system that SET focuses on is aluminum indium gallium nitride (AlInGaN). Using a patent-pending process called pulsed atomic layer epitaxy (PALE), the company is fabricating this material into devices called metal oxide semiconducting heterostructure field effect transistors or MOSHFETs.

While PALE-fabbed AlInGaN MOSHFETs sound a lot like alphabet soup, the devices address many of the problems that researchers working in wide bandgap semiconductors are grappling with today. "At present, nearly all the development work has focused on conventional high electron mobility transistor (HEMT) devices on sapphire and insulating silicon carbide substrates. But several key problems impede commercial development of these devices, such as gate leakage and current collapse, which reduces radio frequency power capacity," explained Dr. Remis Gaska, SET's president.

By using PALE to deposit AlInGaN, the researchers can pulse the material into the system, layer by layer, thus forming a high-quality heterointerface between the various layers of the device. Owing to the deposited silicon dioxide layer, gate leakage is reduced by four to six orders of magnitude, saturation current goes up, and DC and RF characteristics stay the same as, or are even better than, those for conventional HFETs. SET has initiated another Phase I MDA SBIR contract to develop a double heterostructure field-effect transistor to address current collapse. By combining the two technologies, the company will be able to make devices that address gate leakage and current collapse. Initial testing this March provided very promising results.

The 10-employee SET is southbound to Columbia, SC, to be with its university collaborator, Dr. Asif Khan at the University of South Carolina. (The company originally spun out as a result of research conducted by Dr. Michael Shur at Rensselaer Polytechnic Institute.) SET is pursuing three key commercial areas: (1) RF electronics for radar and wireless communications, such as ultra-high power base stations and satellite communications; (2) ultraviolet light emitters for bio-agent detection, biomedicine, and water purification systems; and (3) solid-state lighting. "Our fully vertically integrated material growth/device fabrication facility buildup is in progress in Columbia and most of SET operations are expected to be transferred this fall," said Dr. Gaska. "Our goal is to become a major supplier of materials and devices for emerging high-power RF electronic, visible-ultraviolet optoelectronic, and solid-state lighting markets." SET is looking for future investment in the technology at its facilities in South Carolina.

—L. Aitcheson

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ADVANCED MATERIALS

GALLIUM NITRIDE: THE MATERIAL BEHIND IMPROVED ELECTRONICS

All cellular phone users have experienced a static-filled conversation, dropped call, or no service silence. RF Micro Devices, Inc. (RFMD; Greensboro, NC), is focusing a portion of its company on improving telecommunications by using gallium nitride (GaN)-based semiconductor materials to fabricate next-generation electronic devices.

GaN performs beyond the capabilities of silicon, gallium arsenide (GaAs), and indium phosphide (InP). The researchers at RFMD are developing GaN power amplifiers for cellular phone base stations, a $1 billion industry. GaN transistors have at least ten times the power density of conventional GaAs and silicon devices.

Using research performed at Cornell University, which was funded by BMDO, the Joint Service Electronics Program, and the Defense Advanced Research Project Agency's Optoelectronics Technology Center, RFMD is manufacturing epitaxial wafers of GaN-on-sapphire and GaN-on-silicon carbide (SiC). The company is expanding into manufacturing GaN-on-sapphire high-electron mobility transistors (HEMT) for power amplifiers. These devices offer higher frequency performance and superior power performance over GaN-on-silicon.

In order to develop GaN power amplifiers for the wireless infrastructure market, RFMD acquired RF Nitro in October 2001. RF Nitro licensed two exclusive patents to use Cornell University's flow modulation epitaxy (FME) process for fabricating compound semiconductors. BMDO partially funded FME, an advanced version of organometallic vapor phase epitaxy, for the development of wideband gap electronic devices for high-power applications.

RFMD has begun qualification testing of its GaN devices and expects to be sampling transistors by the middle of 2003. The company's GaN fabrication facility in Charlotte, NC, can manufacture 5,000 four-inch wafers per year. The number of GaN devices produced per year will depend on the application and layout of each transistor.

The company also is using FME to develop GaN devices on SiC. However, this substrate is too expensive for commercial use. RFMD's capabilities for the fabrication of GaN-on-SiC HEMTs are best suited to DOD applications. The company is working with the U.S. Air Force RF Nitride Device Enhanced Readiness program to examine reliability and device issues related to GaN HEMT. "We see great commercial business opportunities for GaN, and we're really focused on that," said Joseph Smart of RFMD. "However, we remain interested in DOD applications."

—T. Spitzer

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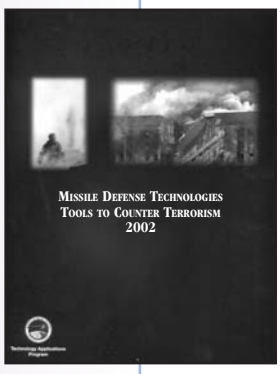
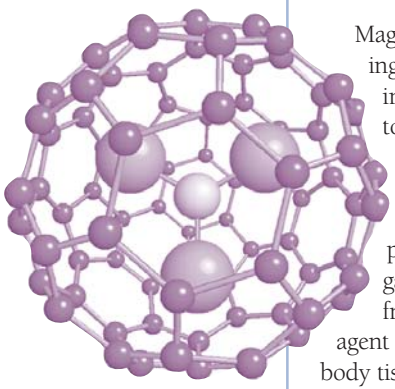
Tower power. *RFMD is making gallium nitride-based power amplifiers that are key to wireless communications technology. These amplifiers will be used in cellular phone towers and base stations across the country.*

MDA Technologies Help Counter Terrorism

The new publication *Missile Defense Technologies—Tools to Counter Terrorism* is now available in print. Developed by the MDA Office of Technology Applications, the illustrated 32-page report highlights 18 MDA-funded technologies that are currently or will soon be available for counter-terrorism applications. Three application areas are covered: Chemical and Biological Countermeasures, Surveillance and Information Collection, and Cyber Warfare. To order your free copy, call (703) 518-8800 ext. 500. Leave your name, mailing address, telephone number, and the name of the publication. The report can also be viewed online at www.acq.osd.mil/bmdo/bmdolink/html/pubs.htm.



METALLOFULLERENES STARTING TO LIVE UP TO THEIR POTENTIAL



Magnetic resonance imaging (MRI) is a common imaging technique used to find tumors and other anomalies inside the human body. Although infrequent, patients can suffer from gadolinium poisoning from the MRI contrast agent used to image critical body tissues. Nausea, vomiting, allergic-type reactions, headaches, dizziness, chills, fainting, and occasionally convulsions are among the list of side effects that a patient can also experience.

Making molecules. *To make trimetaspheres, the first step involves a reactor technician packing a graphite rod with a scandium and graphite powder mixture. The rod is put into the reactor and burned to soot, which is then separated.*

Luna Innovations, Inc. (Blacksburg, VA), is developing a technology that can make safer MRI contrast agents, more effective radiopharmaceuticals, and better performing nonlinear optical and electronic devices. Luna is producing metallofullerenes they named trimetaspheres which, as shown above, are small, soccer-ball-shaped molecules containing up to three different metal atoms and a nitrogen atom enclosed in a cage of carbon. Rare earth metals, such as gadolinium and a few group 3B elements, can be incorporated inside the cage.

Generally, metallofullerenes have been discredited in the past because they were sensitive, easily decomposed, and researchers failed to reliably produce them with an acceptable yield. However, Luna is capable of producing highly stable trimetaspheres with high yields leading to a wide array of applications. "The beautiful, strategic, scientific advantage to having this particular class of molecules is that to tune a specific application you just pick a different metal," said Dr. Steve Stevenson, senior research scientist at Luna.

In 2001, BMDO awarded Luna a Phase I SBIR to develop a new technique for creating self-assembled sensors and molecular computation systems. The original research was aimed at developing a totally new class of molecular systems with applications in chemical/molecular computing using trimetaspheres. Insight gained from the work in the BMDO SBIR Phase I has enhanced the effort to develop improved MRI contrast agents by trapping gadolinium in the carbon cage, which prevents adverse reactions and gives the agents better relaxivity. Testing has also shown that the unique nanomaterial improves the ability to image critical body tissues and reduces the amount of agent needed. Luna recently received a $2 million Advanced Technology Program grant from the National Institute of Standards and Technology (NIST) to pursue the development of MRI contrast agents.

The second year of Luna's NIST grant is supporting research to selectively functionalize the cage to make cell targeted contrast agents. By attaching the right chemical functional group to the trimetaspheres, Luna can make them bind to a certain spot in the body. In addition to serving simply as a targeted contrast agent, gadolinium trimetaspheres can be combined with radioactive holmium to simultaneously provide radiation therapy and imaging for cancer patients, making radiopharmaceuticals more effective by allowing them to target only tumor cells.

The medical world is not the only field that can benefit from Luna's trimetaspheres. Nonlinear optical devices such as thin films can be made by using erbium inside the cage. For electronic device applications, variable capacitance thin-film dielectrics can also be made. Luna has used its ionic self-assembled monolayer technique to deposit variable capacitance, thin-film, dielectric trimetasphere layers. By changing the strength of the electric field to which the thin-film is exposed, the capacitance of the film can be varied.

Luna has exclusive licenses with Virginia Tech allowing the company to manufacture as well as research and develop trimetaspheres. Currently, it is producing trimetaspheres and has held discussions with potential partners regarding production of optical devices and MRI contrast agents. Luna is interested in developing new applications for its technology.

—T. Spitzer

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LASERS

TUNABLE LASER MADE MORE AFFORDABLE

A 1550-nm tunable laser that costs less than half as much as competing semiconductor-based devices may soon help optical networks operate more economically and flexibly.

With BMDO SBIR funding, Photera Technologies, Inc. (San Diego, CA), has developed a new diode-pumped solid-state laser capable of very high output powers, extremely narrow spectral widths, and rapid tunabilility in the C- and L-bands (1530 to 1605 nm). Photera's product, which has already reached the prototype stage, is projected to cost less than $1,000 per unit, compared with roughly $2,500 for today's semiconductor tunable lasers.

"From the beginning, we wanted to design a laser that was amenable to low-cost manufacturing," said Photera's Eric Takeuchi, a senior staff scientist. "By using readily available components that can be assembled with today's pick-and-place automated equipment, the cost to manufacture our device will be significantly less. With many different tunable laser designs becoming commercially available in the next year, it is very important for us to not only be extremely competitive in terms of performance, but also cost."

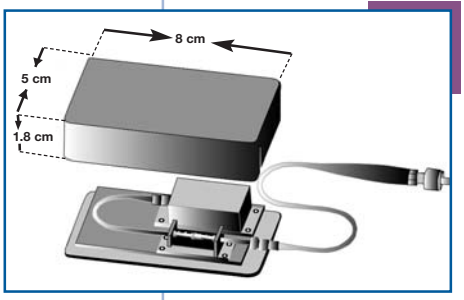
Tunable lasers potentially solve a logistics headache. The advent of wavelength-division multiplexing (WDM) allows multiple wavelengths of light to share the same fiber-optic cable. But it takes one laser to produce each of those wavelengths, and as the power of WDM has grown to 160 wavelengths per fiber, the collection of lasers needed has become unwieldy.

Instead of networks using hundreds of fixed-wavelength lasers, they could use only a handful of tunable types. Because such networks are not yet widely deployed, the most common application for tunable lasers today is sparing, or serving as backup replacements for fixed-wavelength lasers. This allows operators to reduce the number of fixed laser spares that must be kept in inventory, saving money.

More exciting is the prospect of remote service provisioning. This capability would allow service providers to remotely reconfigure the wavelengths used by a specific customer to provide additional "bandwidth on demand." It could also help switch bottlenecked traffic to uncrowded wavelengths, allowing networks to operate at greater capacities.

Photera's tunable laser stems from research it has undertaken for BMDO's SBIR program. In 1999, BMDO awarded Photera a Phase I contract to develop a prototype for missile defense applications. The ability to rapidly tune amongst a large number of wavelengths in the 1550-nm range would enable increasingly robust and sophisticated sensors for laser radar-based missile detection, identification, and tracking systems. Photera has proposed to further develop this laser through a Phase II project, now being considered by MDA.

The basis of the device is a co-doped ytterbium-erbium (Yb-Er): glass gain medium optically pumped by a conventional broad stripe diode laser, which emits around 980 nm. In this medium, the Yb ions efficiently absorb 980-nm radiation and transfer their energy to the Er ions, which emit laser light around 1550 nm. A polarizing element and an electro-optic birefringent filter provide very stable single-frequency operation and rapid wavelength tunability. The resonator is completed by an end mirror that provides the requisite output coupling. Output from the laser is coupled to a single-mode fiber.



Price is right. *For less than $1,000 per unit, optical networking companies will soon be able to buy 1550-nm tunable laser technology with high output powers, extremely narrow line widths, and rapid turnabilitty.*

The laser's output is provided via an optical fiber that is part of the laser resonator itself. Having an optical fiber output simplifies coupling of the laser to the system, eliminating the need to align a separate output fiber to the laser.

Photera seeks corporate or other private sources of funding to help bring its innovative tunable laser technology to market. The company is also looking for investment capital.

—P. Hartary

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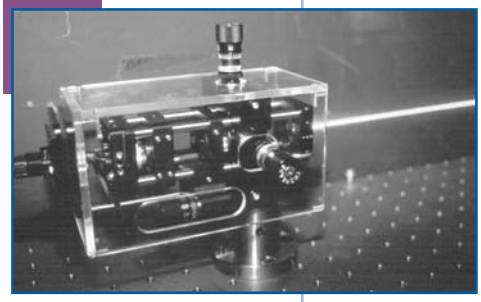
LASERS

ARGON-ION LASER: SOLID-STATE REPLACEMENT FOUND



Rival in the making? *AdvR is using its KTP waveguide to double the frequency of a laser beam from 976 nm to 488 nm, creating a new solid-state alternative to the argon-ion laser.*

Doctors call chronic glaucoma the "sneak thief in the night." The darkness creeps in gradually from the outer edges of your vision, blocking images that were once seen. Slowly, the blackness progresses inward until you feel like you are seeing the world through a tunnel. Finally, there is blackness, and you are blind.

According to WebMD™ Health, glaucoma occurs when the optic nerve, which transmits visual messages to the brain, is slowly destroyed by increased pressure in the eye. The disease affects about 3 million Americans and is one of the leading causes of blindness. Surgeons have been using the argon-ion laser for decades to successfully treat patients with glaucoma. However, this device is bulky, very inefficient, and prone to overheating.

AdvR, Inc. (Bozeman, MT), is developing a potential replacement: a 488-nm diode laser that offers higher performance than conventional argon-ion lasers. AdvR's laser also allows for direct modulation of the blue light, which is not offered in other devices. The new laser is more compact, requires less power to operate, and does not need cooling. It is more cost effective to operate as well.

BMDO funded AdvR to develop a compact 488-nm diode laser as a solid-state replacement for the argon-ion laser. AdvR licensed the technology patents from DuPont, which originally developed the blue diode laser for read/write compact discs.

The argon-ion laser was invented in 1964 and has since been used for medical treatment and research, DNA sequencing, wafer and mask inspection, graphic arts, bioanalytical applications, cell sorting, and hematology. Therefore, the dyes that cause things to fluoresce were manufactured to have a large absorption in the 488-nm regime. In one of its most common applications, the 488-nm light excites fluorescent dyes for gene sequencing. To take advantage of those dyes, AdvR hopes to provide a more efficient 488-nm light at less cost.

AdvR is using its patented potassium titanyl phosphate (KTP) waveguides to frequency double a 976-nm laser beam to 488 nm. KTP is a nonlinear optical material that is easy to fabricate into waveguides. The company's KTP waveguides can be used for quasiphase matched structures for frequency doubling and sum and difference frequency generation. They contain embedded Bragg gratings for diode laser stabilization, pulse compression, and notch filters. Advantages of the KTP waveguide include a transparent window ranging between 400 and 4500 nm in size, high damage threshold, and large electro-optic coefficient.

AdvR has recently received additional funding from MDA to pursue domain engineering in a new substrate material called stoichiometric lithium tantalate, which is more cost effective, can be grown larger, and has the capability to do other frequency conversions. However, this research is still preliminary.

Currently, AdvR manufactures and sells fabricated chips containing KTP waveguides. They are also developing the compact 488-nm diode laser using these waveguides as a solid-state replacement for the argon-ion laser. They are not targeting any specific application of the argon-ion laser, such as DNA sequencing or medical uses, although they all apply. "Our philosophy has been, we are building a better light bulb," said Phillip Battle, AdvR's vice president of technology.

—T. Spitzer

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"Man will occationally stumble over the truth, but most of the time he will pick himself up and continue."

Winston Churchill

REAL-WORLD SUPERCONDUCTIVITY

High-temperature superconducting (HTS) wire offers theoretical advantages over copper wire for use in lightweight, multimegawatt generators. The problem is getting HTS wire to achieve its promise under real-world conditions.

With initial funding from BMDO and the U.S. Air Force, LEI (Pittsburgh, PA) is building a two-megawatt HTS rotor that will serve as a testbed for studying how reliably and efficiently coils made from superconducting wire perform in realistic environments. Such equipment will help engineers determine the best coil and rotor designs for a practical lightweight generator rated at one megawatt and above.

In 1997, BMDO funded an SBIR Phase I contract with Heston Consulting Company, Inc., which spun off LEI, to assess state-of-the-art cryogenic generators for mobile military applications and to suggest possible design criteria for building one. In 1998, BMDO awarded Heston a follow-up Phase II contract to design, build, and test a one-megawatt HTS rotor. The company was not able to find matching funding, however, and the project lapsed into quiescence. In 2002, the U.S. Air Force awarded LEI a new Phase II SBIR contract with the objective of building a two-megawatt HTS rotor and generator testbed.

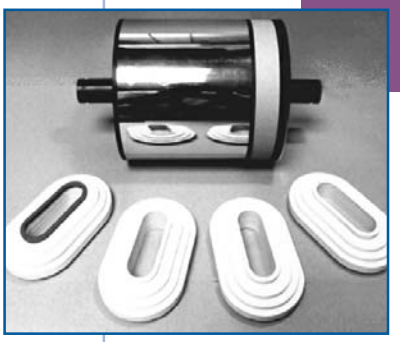
What started out as a generator program has evolved into a long-term test facility. Since new superconductor technologies are being invented all the time, LEI is designing the HTS rotor housing to be modular so that the equipment will accept any kind of coolant and any kind of conducting wire. This will enable researchers to test multiple configurations.

HTS wire such as yttrium barium copper oxide affords a significantly higher current density (and lower losses) than copper wire, which means that an all-superconducting generator might have only 10 percent the weight of a conventional machine. The problem is that superconducting wire must be cooled to very low temperatures, requiring refrigeration equipment that introduces a weight penalty. For small-scale generators on the order of 50 to 150 kilowatts, a superconducting generator makes no sense from either a cost or weight point of view.

LEI estimates that the crossover point is somewhere between one and two megawatts—at some point in that multimegawatt range, the weight penalty of cooling HTS wire is less than the weight penalty of using older, more established iron and copper technology. LEI is frank about the economics of superconducting generators: they are never going to be cheaper than conventional machines, and it may be a long time before superconducting systems are as reliable as existing generators. Their main advantage will be in weight critical applications.

LEI's test equipment will provide important clues for designing lightweight HTS generators that will be capable of producing short bursts of four or more megawatts of power for missions such as emitting electronic pulses or powering airborne lasers. LEI welcomes inquiries from organizations who want to fund this effort and make superconductor generator technology a reality.

—A. Gruen



Four coils and a rotor. *LEI's two-megawatt high-temperature superconducting generator will test new technologies in a real-world environment.*

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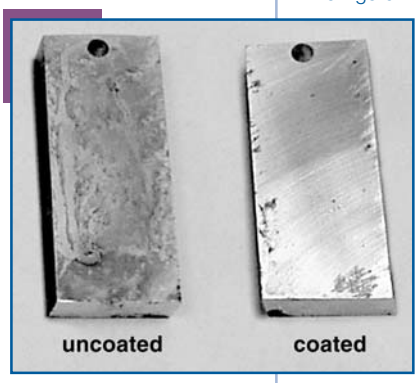
Attention Researchers

Want to be featured in the MDA Update*? If your company is developing an MDA-funded technology that has strong commercial potential, call editor Patrick Hartary at (703) 518-8800, ext. 222. We can help spread the word about your innovation to the media, large commercial businesses, venture capitalists, associations, and other government agencies.*

FEATURE

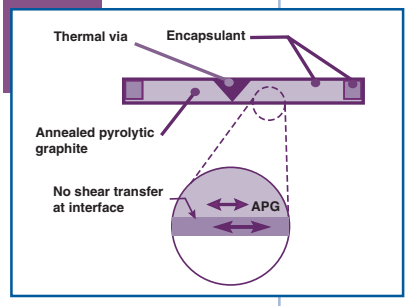
The Age of . . . from page 1



It's not the heat. *It's the humidity. Pictured above is uncoated and Cerablak™-coated aluminum after 36 hours in salt fog.*

that Cerablak did not even need to be black. Through modifications to the low-cost precursor, Applied Thin Films has synthesized "white" Cerablak which retains all other properties. Thin films of Cerablak are continuous, dense, uniform, and transparent.

In addition to its attractive properties of heat and corrosion resistance, Cerablak has four other important advantages. It provides a hermetic seal for continuous coverage and is virtually free of defects. It is simple to make. It is easy to apply by spraying or brushing the solution upon a substrate or even by dipping a substrate in the solution.



High-tech sandwich. *K-Core™ wraps carbon fiber composite around a graphite core.*

Lastly, Cerablak can be formed as a nanocomposite where nanocrystalline inclusions are created *in-situ* and are encapsulated in an amorphous matrix. Such inclusions can induce or enhance chemical, optical, physical, thermal, and mechanical properties. The company says that the "first generation" of Cerablak is monolithic (meaning no inclusions). Looking ahead to the future, however, the material could be used as a stable host to encapsulate nanocrystalline inclusions.

Cerablak can be applied to glass, metal, or other ceramic composites. While it has high temperature resistance useful for coating spacecraft tiles or rocket nozzles, and has inclusion potential useful for electronics and photonics applications, its hydrophobic characteristics can also be used for more mundane purposes such as self-cleaning windows. Applied Thin Films invites inquiries from interested parties who would like to learn more or to fund applied research on this new material.

k-Core™

Circuit boards run hotter than ever. A new thermal material system named k-Core™ cools five times better than aluminum for the same amount of weight.

It's a high-tech sandwich: an encapsulating material (such as aluminum alloy or carbon fiber) is wrapped around a substance that makes up the inner core (such as annealed pyrolytic graphite or APG). Epoxied or soldered to a circuit board, the inner core whisks away heat while the encapsulant holds the core in place. kTechnology Corporation (kTC; Fort Washington, PA) was formed in 1994 to bring k-Core to the marketplace.

In 1998, BMDO funded the company with an SBIR Phase I contract to demonstrate the feasibility of encapsulating APG with a carbon fiber composite (CFC) as packaging to cool a lithium-ion battery, which kTC successfully proved. In 1999, BMDO funded the company with a follow-on Phase II contract to develop the material further and to qualify the material for use in a flight battery bracket assembly.

kTC's secret to success is relatively simple: it can tailor k-Core to produce very specific thermal management results within tight space and weight limits. CFC encapsulant provides stiffness, conductivity, low outgassing, and low coefficient of thermal expansion (CTE). APG provides the bulk of the in-plane conductivity. Together, the two materials work as one (the CFC does not delaminate when transporting heat) and the thickness of a k-Core plate might be less than one half-inch, taking up less space than aluminum. But kTechnology engineers also want a good CTE match between the encapsulant and the part itself, so they might switch from CFC to an aluminum alloy encapsulant or other materials, depending upon the application requirements. kTC can add more APG to the inner core to increase thermal conductivity further with small increases in mass and size, where user constraints allow and extra performance is needed.

k-Core is still on the order of three times more expensive than aluminum heat sinks. The new material system would flourish best where the need for performance, under strict weight and reliability budgets, trumps the desire for reduced cost. However, recognizing the potential benefits to military and avionics systems across the board, MDA continues to work with kTC on other contracts to drive production costs down.

kTC has already sold k-Core-type solutions (just not under the k-Core label) to aerospace companies, which

Continued on page 15

FEATURE

The Age of . . . from page 14

use them in satellites, aircraft, and other military and industrial applications. The company also hopes to extend its business to customers needing high-end passive thermal management systems for terrestrial uses.

Pyrograf-III®

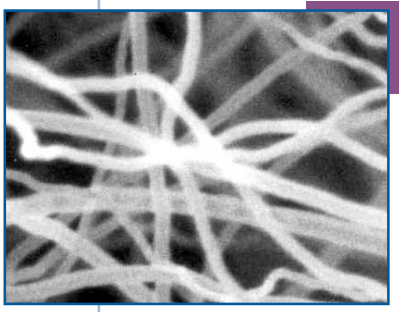
What's old is new again. Vapor grown carbon fiber (VGCF) is such an ancient technology that the Strategic Defense Initiative Organization (SDIO), the precursor to BMDO, funded it as early as 1988. Today, Pyrograf Products, Inc., a subsidiary of Applied Sciences, Inc. (ASI; Cedarville, OH), can produce 70,000 pounds of carbon nanofiber per year—and hopes to one day build a full-scale production plant meeting projected demand for three million pounds per year.

A significant property of carbon fiber has been known since the early 1980s: when added to polymers, it improves their electrical conductivity. The advantage of adding nanofiber (VGCF at diameters of 100 to 200 nm) is twofold: they do not disturb the other properties of the polymer; and the nanofiber only takes up 5 to 20 percent of the volume required by bulkier additives. VGCF has thermal conductivity of 2000 W/m-K, or more than five times that of copper. VGCF also boasts high mechanical strength, which makes it an intriguing prospect as a substitute for metal and fiberglass.

Any reasonably equipped laboratory can introduce a gas-phase catalyst into a heated hydrocarbon atmosphere and produce VGCF. This is how ASI started out in 1985: three people making a few pounds of nanofiber for research purposes. What made ASI different is that the company developed ways of scaling-up production from the laboratory to the factory and patented the process innovations. One of the innovations is surprising: high-sulphur coal is an ideal raw material for the process. Instead of burning it as fuel, ASI can deconstruct it for nanofiber production and generate hydrogen and low-carbon fly ash as usable byproducts.

With funding from SDIO, DOE, and the U.S. Air Force, ASI began to look at applications for the fibers. It joined forces with General Motors and licensed all of GM's intellectual property on VGCF. In 1996, ASI, GM, Goodyear Tire & Rubber Co., and others joined together in a cooperative research agreement and received funding from NIST's Advanced Technology Program. By the year 2000, the Pyrograf Products, Inc., subsidiary had built a pilot plant to produce 35 tons annually of carbon nanofiber, which it called Pyrograf-III®.

Full production remains ASI's true objective. At today's price of more than $85 per pound, carbon nanofiber is still too expensive for all but the most exotic applications. At $10 per pound, it becomes attractive to the automotive and electronics industries. And at $3 or less per pound, it could become an anti-cracking additive for concrete or a structural or electrical additive for tires. The more customers ASI can find, the more it can produce, the lower the cost, and the greater the interest in the product—a virtuous cycle that has the potential to create a whole new industry with benefits to both consumers and coal producers.



Carbon nanofibers. *With lengths of approximately 200 micrometers, nanofibers add important properties to polymers.*

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"Don't let what you cannot do interfere with what you can do."

John Wooden

MDA Update
FALL 2002

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